

**FIRST INTERNATIONAL  
CONFERENCE ON ELECTRON  
MICROSCOPY  
OF NANOSTRUCTURES**

**ELMINA**  **2018**

**ПРВА МЕЂУНАРОДНА  
КОНФЕРЕНЦИЈА О  
ЕЛЕКТРОНСКОЈ МИКРОСКОПИЈИ  
НАНОСТРУКТУРА**



August 27-29, 2018, Belgrade, Serbia  
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FIRST INTERNATIONAL CONFERENCE

ELMINA  2018

PROGRAM



BOOK OF ABSTRACTS

Rectorate of the University of Belgrade, Belgrade, Serbia

August 27-29, 2018

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Organized by:

Serbian Academy of Sciences and Arts and Faculty of Technology and Metallurgy,  
University of Belgrade

Endorsed by:

European Microscopy Society and Federation of European Materials Societies



At the beginning we wish you all welcome to Belgrade and ELMINA2018 International Conference organized by the Serbian Academy of Sciences and Arts and the Faculty of Technology and Metallurgy, University of Belgrade. We are delighted to have such a distinguished lineup of plenary speakers who have agreed to accept an invitation from the Serbian Academy of Sciences and Arts to come to the first in a series of electron microscopy conferences: Electron Microscopy of Nanostructures, ELMINA2018. We will consider making it an annual event in Belgrade, due to this year's overwhelming response of invited speakers and young researchers. The scope of ELMINA2018 will be focused on electron microscopy, which provides structural, chemical and electronic information at atomic scale, applied to nanoscience and nanotechnology (physics, chemistry, materials science, earth and life sciences), as well as advances in experimental and theoretical approaches, essential for interpretation of experimental data and research guidance. It will highlight recent progress in instrumentation, imaging and data analysis, large data set handling, as well as time and environment dependent processes. The scientific program contains the following topics:

- Instrumentation and New Methods
- Diffraction and Crystallography
- HRTEM and Electron Holography
- Analytical Microscopy (EDS and EELS)
- Nanoscience and Nanotechnology
- Life Sciences

To put this Conference in proper prospective, we would like to remind you that everything related to nanoscience and nanotechnology started 30 to 40 years ago as a long term objective, and even then it was obvious that transmission electron microscopy (TEM) must play an important role, as it was the only method capable of analyzing objects at the nanometer scale. The reason was very simple - at that time, an electron microscope was the only instrument capable of detecting the location of atoms, making it today possible to control synthesis of objects at the nanoscale with atomic precision. Electron microscopy is also one of the most important drivers of development and innovation in the fields of nanoscience and nanotechnology relevant for many areas of research such as biology, medicine, physics, chemistry, etc. We are very proud that a large number of contributions came from young researchers and students which was one of the most important objectives of ELMINA2018, and which indicates the importance of electron microscopy in various research fields. We are happy to present this book, comprising of the Conference program and abstracts, which will be presented at ELMINA2018 International Conference. We wish you all a wonderful and enjoyable stay in Belgrade.

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## Metal Nanoparticles-PANI Nanocomposites and their Applications

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Characteristic physicochemical properties, as the effect of their nano - dimensions and diversity of their possible applications, make metallic nanoparticles (NPs) one of the main colloidal materials studied in the nanoscience field. Its development depends on the improvement of the existing synthetic procedures in order to gain stable and uniform metallic NPs with different sizes and shapes, since NPs' features (optical, electrical, catalytical, *etc.*), and therefore their applications, depend on particles' morphology. The necessities could be fulfilled within materials such nanocomposites are, *ie.*, by the incorporation of metallic NPs into the polymer matrix, whereby not only polymer matrix will have a positive effect on the NPs characteristics, but metal NPs could significantly improve polymers' properties. A special group of functional materials with advanced features and accordingly promising applications are nanocomposites with metal NPs (gold (Au), silver (Ag), and copper (Cu)) and intrinsically conductive polymers, such as polyaniline (PANI). As biocompatible materials with unique properties, good conductivity and electrochemical activity, these nanocomposites were the subject of our researches [1-3].

Nanocomposites designated as Au-PANI, Ag-PANI, and Cu-PANI, were synthesized by the simple *in situ* oxidative polymerization of aniline to PANI by metal ions [1-3]. These typical oxido-reduction reactions begin with atomic (metal ions) and molecular (aniline monomer) precursors in an appropriate molar ratio, in order to achieve simultaneous reduction of metal ions to NPs and oxidation/polymerization of aniline to PANI. This type of nanocomposite' formation has certain advantages over other chemical or electrochemical polymerization processes, that are associated to reduced number of reactants, since metal ions such  $\text{Au}^{3+}$ ,  $\text{Ag}^+$ , and  $\text{Cu}^{2+}$  have

satisfactory standard electrode potentials (+1,498, +0,8, and +0,34 V, respectively), that will easily induce aniline oxidation, while formed PANI chains act as surfactants that will stabilize metal NPs through charge transfer. Additionally, it is less demanding, either in the process itself, or in the post-synthetic treatment (concerning the cleaning of the sample).

Based on our findings [1-3], as well as existing literature data, experimental conditions have great influence on the nanocomposites' features firstly reflected through their morphology (size and shape of metallic NPs and PANI chains), and consequently possible applications. For example, changing the reaction medium (water/methanol), pH of the reaction mixture, as well as the molar ratio between reactants [1], has a significant effect on the structure and morphology of the final products. These factors control the duration of the polymerization induction period, which will further affect the other stages of the polymerization, and finally nanocomposites' characteristics. Thus, the architecture of formed AgNPs varies from 7 nm to 150 nm in sizes and from spheres, through triangular nanoplates, to polyhedral shapes, while PANI chains are formed either in the shape of fibers or granules. Besides, their conductivity, electrocatalytic activity, and possible application for oxygen reduction reaction (ORR) differ, and vary depending on AgNPs dispersion throughout PANI matrix.

Similar behavior was recognized with Au-PANI nanocomposite [2]. It was shown that the molar ratio between  $\text{Au}^{3+}$  ions and aniline is crucial for the nature of the final product - just for the defined proportion between these two reactants, the final product is Au-PANI nanocomposite, with granular morphology and incorporated Au nanorods. Additionally, even though this nanocomposite have similar or half smaller mass fraction of metal NPs, compared to Ag-PANI nanocomposites mentioned above (~29 wt% compared to ~20 and ~45 wt%), its electrical conductivity is several order of magnitudes higher. The main reason could be the dispersity of NPs throughout PANI matrix and their morphology. Namely, since the electrical conductivity of nanocomposites is narrowly correlated to its network geometry, AuNPs adsorbed on the PANI chains surface could act as charge trapping sites that participate in the charge transport through PANI matrix, enabling the formation of infinite conductive pathways, unlike Ag-PANI nanocomposites, where these pathways are interrupted by polyvinylpyrrolidone non-conductive islands [1].

Besides they are electrocatalytically active, metal/PANI nanocomposites also show significant antimicrobial activity [3]. Our findings considering Cu-PANI nanocomposite, with fibrillar PANI chains morphology and spherical CuNPs with 10 nm in diameter, pointed out that small amount of this composite for short contact time (all compared to the literature data) can inhibit the growth and kill representative microbes - *Escherichia coli*, *Staphylococcus aureus*, and *Candida albicans*. There

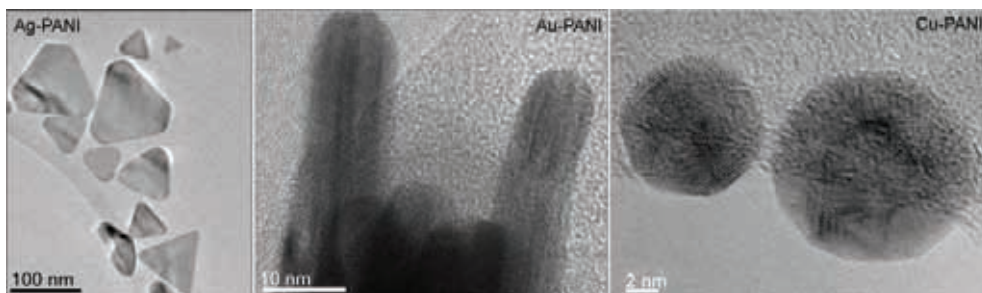


is a synergistic antimicrobial effect of nanocomposite' constituents, that is a combination of several different action mechanisms: a) physical and electrostatic interaction between nanocomposite and microbial cell wall; b) as a steric stabilizer, PANI chains network increases effective concentration of strong antimicrobial agent - CuNPs, and contact interface between nanocomposite and microbes; c) additional antimicrobial effect of released  $\text{Cu}^{2+}$  ions.

The electrochemical and antimicrobial activity of these nanocomposites, regardless metal mass fraction, NPs' size, shape, and PANI morphology, is related to the particles' surface effects, *ie.*, reactive (111) crystallographic planes present on the particles' surface. These nanocomposites proved to be promising Pt-free electrocatalysts and antimicrobial agents.

#### Reference

- [1] U Stamenović *et al*, Article in Press.
- [2] U Bogdanović *et al*, ACS Applied Materials and Interfaces **7** (2015), 28393.
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- [4] This work was supported by grants from the Ministry of Education, Science and Technological Development of the Republic of Serbia (No. 172056 and 45020).



**Figure 1.** TEM images of metal nanoparticles-PANI nanocomposites.

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